Original Article

Evaluation of Gaseous Pollutants Emission Rate from Marvdasht Landfills

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Abstract

Unmanaged gasses emitted from the landfills can lead to various environmental and health problems for the resident of such regions. Despite various studies conducted on prediction of emission rates of gaseous pollutant in landfills, no study in currently being conducted on the emission rates of carbon dioxide, methane, and non-methane organic compounds from the Marvdasht landfills. In the first steps of this study the required information were gathered first and then the necessary prediction calculations were handled by the LandGEM software. The study results suggest that the within the years of 2003 and 2031, the generation rates of carbon dioxide, methane and non-methane organic compounds will respectively be equal to 14×10^{11}, 4667×10^{7} and 3.89×10^{5} tons. Among the aforementioned gasses, in case of converting the methane energy capacity into the electrical energy, a total income of 1489 billion rials is achievable from the Marvdasht landfill within a course of 27 years of operation. However, it should be noted that no investigation was conducted on the initial and operation costs in this study. In this study, by calculating all of the required information for the design and construction of a biogas collection and extraction system in the landfill of Marvdasht, the necessary means for the appliance of such plan has been provided.

Keywords: Landfill, Gaseous pollutants, Methane, Carbon dioxide, NMOCs, Marvdasht

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Introduction

Inappropriate management of landfills can lead to the pollution of atmosphere, soil and water. Thus conducting vast studies for the purpose of preventing such pollutions is deemed necessary. Water and atmosphere are among the environmental factors for which they play the superior role in site selection process of landfills. Among the important environmental factors climatic elements, temperature, precipitation, wind and sun radiations play the superior role compared to the other climatic elements. The temperature and humidity are the main determining factors for the type and course of the decomposition of solid waste. The wind however plays the considerable role in transferring the generated suspended particles and gasses (1). The municipal landfills are utilized for the purpose of reducing the environmental impacts of the generated solid waste. The landfills can turn into an environmental tragedy in case of inappropriate design and management (2). For the purpose of minimizing the potential risks of landfills a scientific based site selection is necessary. In site selection procedure of landfills various factors including surface and underground water pollution, economic factors, geological features, wind direction, roads, airports and mines positioning etc, must be considered in order to provide the best possible options for the construction of a landfill. The intensive growth of solid waste generation shows the crucial role of a comprehensive management plan in human health.

The city of Marvdasht is located in the Fars province, 35 km from the north of Shiraz with mild and mountainous climate. The population of this city is 137087 based on the 2011 capitation.Marvdasht is one the northern cities of Fars province with an altitude of 1620 meters from the sea surface and the area of 4649 km2. This region is geographically ideal and with mild climate, ample water sources and appropriate soil.

The city of Marvdasht in currently facing a daily waste generation rate of 80 tons which requires several long term and short term plans, including management of their solid waste disposal and recycling. The city officials have considered a temporary location for the land filling operation which faces several issues which includes inappropriate location in direction of cities' development, incomplete landfill site, approximation to farm lands and nearby villages and unapplied secure disposal. According to researchers such as Entezari (2012) the relocation of this landfill to a more suitable location is necessary due to the various issue mentioned above (3).

The recent solid waste landfills projects include the design and installation of controlling equipments for the transference of the generated landfill biogas for energy generation (4). Uncontrolled leachate and biogas emissions from the solid waste landfills can cause harmful effects for the environment (5). The emitted gasses from the landfills are also called LFG which are generated through biochemical reactions on decomposable organic compounds under anaerobic condition. The dominant landfill gasses include methane, carbon dioxide, hydrogen gasses, hydrogen sulfide, volatile organic compounds etc(6).Omrani et al.(2008) investigated the collection conditions of methane from the landfill of Shiraz (7). This study has investigated the collection conditions of methane by considering the technical, financial and hygienic aspects. Their study results suggested that the produced biogas from the landfills contains 61% methane and 24% carbon dioxide. Every cubic meter of methane gas is equal to (added)an energy capacity of 5.22 kw/h of electricity. If we were to consider an electricity generation efficiency of 30%, the generation capacity of every cubic meter of methane would decrease to 1.56 kw/h (4). Evaluation of solid waste moisture effect on biogas generation rate in landfills was studied by Zoghi et al. (2011). In this study, the landfill of Saravan, one of the other cities of Iran, was modeled by using the LandGEM software which calculated the amount of output biogas in various years. The obtained results illustrate that the production rate of gas in humid conditions is 3.85 times more than the dry conditions. The maximum methane, carbon dioxide and NMVOCs generation in this landfill under humid conditions is respectively equal to 32110, 11700 and 500 tons per year and under dry condition is respectively equal to 8349, 3043 and 130 tons per year (8). Ahmadiet al(2014) conducted a research on the generation rates of greenhouse gasses like methane and carbon dioxide in the landfill of AradKooh, another city of Iran,throughout a course of 30 years by using a first order decomposition rate equation (9). The obtained results suggested that the gas generation in the landfill would experience a fall after the shutdown. The maximum methane and carbon dioxide rates were observed respectively at 616 million kg in 2015 and the minimum generation rates were observed at respectively 0.3 and 0.8 million kg in 2044. The overall volume of generated gas by this landfill is estimated at 213 million cubic meters within 30 years, 24 percent of which is comprised of methane and 73 percent of carbon dioxide (9).

Methane is one of the greenhouse gasses with approximately 12 years of lifespan. The decreased global production of methane can entail considerable positive and swift effects on the global warming (10). Studies show that the average global temperature in the last year has increase by 0.3 and 0.6 ˚C (11). Currently the dominant approach in inhibiting the generated gas from the landfills in Iran is through extraction and burning. However, most of these landfills in Iran are devoid of the minimal necessary equipment for the extraction and combustion of the generated biogas. Appliance of recycling methods of solid waste such as composting can also reduce amount of solid waste and the landfill's area (12). The evaluation and estimation of emission and generation rates of biogases from the landfills for the purpose of design and successful extraction of energy is highly important. The generated biogas in the landfills could directly be used for production of required energy in various industries including the lightening, gas turbines and generators (7). The emission of biogases generated in landfills entail various potential effects on the environment some of which are fire, explosion, health risks, destruction of agricultural products, the pollution of underground waters, global warming of atmosphere and dissatisfaction with the generated odor (6).

Although, several other studies have investigated the generation and emission of pollutants from landfills, however no current study is presented for the landfills of Marvdasht. This investigation is conducted for the general purpose of determining the emission rates of carbon dioxide, methane and 48 NMOCs in the landfills of Marvdasht and their various consequences from different perspectives including environmental, technical and health. We have also investigated the pollutants dispersion into the nearby regions using various available models.

Methods and Materials

- *Study region*

The previous landfill of Marvdasht is located near the Persepolis crossroads which is closed since the year 2002 due to the lack of space and proximity to the city.

Figure 1. A snapshot from Marvdasht landfill (A) and unloaded waste in the site for the purpose of disposal (B).

The LandGem software package is developed by the control and technology center which is affiliated with the United States environmental protection agency which could be used for the automatic prediction and modeling of gas emissions from the municipal landfills [13]. This software package is also capable of estimating the emission rates of NMOCs in addition to the two main gasses which is carbon dioxide and methane [12, 13, 14]. In order to calculate the emission rate of pollutants from the Marvdasht landfill, two factors must be determined: (1) the weight of the solid waste disposed throughout the lifespan of the landfill and (2) the climatic features. The Landfill of Marvdasht has been operational since 2003. Considering the rising population in the city and the efficiency of the municipal waste collection system, the amount of waste delivered for disposal is increased in proportion to last year. According to the records from the Municipal recycling agency of Marvdasht, the amount of delivered waste for disposal was 80 tons per day in 2015. The LandGEM software uses the first order decomposition rate equation for the calculation and estimation of annual emission of gasses from the landfill in specified regions which is handled by the user and it is presented below:

$$Q_{CH4} = \sum_{i=1}^{n} KL_o \left(\frac{M_i}{10}\right) e^{-k*t_{ij}} \quad (1)$$

where QCH4 is the methane generation rate in cubic meter; i is the step index in year; n is the specified year difference for the calculation of gas generation and the year of establishment; J is the interval in 0.1 of the year; k is the methane generation rate in the year-1; Lo is the methane generation potential in m3/ton; Mi is the waste mass in the first operation year in ton and tij is the age of j portion of waste in j years in 0.1 of the year (for instance:3.2 years).

In respect to the climatic features of the region and the precipitation rate of 400 mm/year, we would consider a value of 170 m3/ton.year for the methane generation potential and a value of 0.02 for the methane generation rate by considering the type of the landfill. The Eq.2 is usually used for the calculation of L0.

$$L_o\left(\frac{m^3}{mg}\right) = MCF * DOC * DOCF * F + 1482.8 \qquad (2)$$

where MFC is the correction coefficient of methane which would be equal to 1 in 5 meters of landfill depth and 0.8 in above 5 meters of depth; DOC is the percentage of the decomposable organic carbon; DOCF is the non-similarity coefficient (which is equal to 0.77) and F is the volume percentage of methane in the produced gas in the landfill which is considered within the range of 40% and 60% [7]. We have inputted the landfill descriptions based on Table1 into the LandGEM software.

Landfill Open Year	**2010**	
Landfill Closure Year (with 80-year limit)	2030	
Actual Closure Year (without limit)	2030	
Have Model Calculate Closure Year?	No	
Waste Design Capacity		*Ton*
Methane Generation Rate, k	0.050	*$year^{-1}$*
Potential Methane Generation Capacity, L_o	170	*m^3/Mg*
NMOC Concentration	4,000	*ppmv as hexane*
Methane Content	50	*% by volume*

Table 1. Landfill Characteristics

The population of the city for the future based on the current population and the growth coefficient (r equal of 1.1) was predicted in this study. The Eq.3 was used in order to calculate the population for the following years.

$$P_n = P_0(1 + r)^n \qquad (3)$$

Where Pn is the population in the n year, P0 is the population in the base year, r is the average population growth rate and n is the number of years. In this study, The ScreenView software was utilized to investigate the dispersion of carbon dioxide, methane and NMOCs into the atmosphere. The presented presumptions in Table2 were used in this software.

Parameters	CO2	CH4	NMOCs
Source type	Area	Area	Area
Emission rate	0.0126 gr/s.m3	0.0046 gr/s.m3	0.000197 gr/s.m3
Source release height	0 m	0 m	0 m
Receptor height above ground	1 m	1 m	1 m
Larger side of rectangular area	100 m	100 m	100 m
Smaller side of rectangular area	50 m	50 m	50 m
Search through range of wind direction?	Yes	Yes	Yes
Dispersion coefficient	Urban	Urban	Urban

Table 2. Assumptions and parameter for using Screen View software

order to determine the population growth rate and waste generation

Year	Population	Amount of produced solid waste in year	Amount of accumulated solid waste in landfill	Year	Population	Amount of produced solid waste in year	Amount of accumulated solid waste in landfill
2003	125023	25948	25948	2017	146387	30382	422208
2004	126531	26261	52209	2018	147997	30716	452925
2005	128039	26574	78783	2019	149625	31054	483979
2006	129547	26887	105670	2020	151271	31396	515376
2007	131055	27200	132871	2021	152935	31741	547117
2008	132563	27513	160384	2022	154617	32090	579208
2009	134071	27826	188210	2023	156318	32443	611651
2010	135579	28139	216349	2024	158037	32800	644452
2011	137087	28452	244801	2025	159776	33161	677613
2012	138594	28765	273566	2026	161533	33526	711139
2013	140119	29081	302648	2027	163310	33894	745034
2014	141660	29401	332049	2028	165107	34267	779301
2015	143219	29724	361774	2029	166923	34644	813946
2016	144794	30051	391826	2030	168759	35025	848972

Table 3. Population details and waste generation rate in years 1382 and 1409

Results and Discussions

- ### *The population and waste estimation of future years*

Based on the records from the municipal recycling agency of Marvdasht, 80 tons of solid waste is disposed in the landfill. Therefore the population details of this city were estimated within the years of 2012 and 2030 which is presented in Table 1. By dividing the population of the city in 2011 over the annual waste generation rates of every citizen in Marvdasht, a value of 583 g/day was calculated

In this study a constant value for the waste generation capita and a population growth rate within the years of 2003 and 2030 was assumed in capita in other years. The disposal capacity of the landfill was estimated at 849000 tons based on the gathered information. The operation course of the landfill was estimated at 27 years which is within the years of 2003 and 2030 based on the disposal capacity of the landfill of Marvdasht and the waste generation rate. The estimation of population and waste generation of Marvdaht in the following years are presented in Table 3.

The estimation of the total generated biogas

Biogases are produced as the result of biological degradation of perishable organic matter under anaerobic conditions. Biogases include carbon dioxide, methane and dozens of other toxic chemicals known as non-methane organic compounds. It was revealed that the dominant produced gasses in Marvdasht landfill are methane and carbon dioxide gasses. It is estimated that 170000000 tons of carbon dioxide and 46670000000 tons of methane would be released into the atmosphere within the course of 27 years of landfill operation. In addition to carbon dioxide and methane, a collection of other NMOCs are also produced at the landfill. The generation rate of NMOCs within the course of 27 years of landfill operation is estimated at about 389000 tons. Although, after the operation shutdown in 2030 no other waste is disposed in this landfill, however the production of these biogases is not halted. Based on the estimations conducted by LandGEM software, the volume of the generated gas within 150 years of operation would reach 12×1011 tons of biogas. Table 4 presents the details about the aggregated generation of various gasses at the landfill of Marvdasht within the course of 27 and 150 years. The first order rate equation is the most common way used to predict gas generation in landfills. Amini et al. (2012) reported that generally predictions handled through the first order rate equation are on average lower than actual gas generation. Also, they reported that the uncertainty (coefficient of variation) in gas generation of the first order rate equation varied from ±11% to ±17% at initial years of landfills operation, ±9% to ±18% at the end of waste placement, and ±16% to ±203% for 50 years after landfill closure year [15]. This information shows that accuracy of the first order rate equation for prediction of gas generation can be more accurate for landfill life duration compared to corresponding years after shutdown.

Gas type years	Gas generation potential within 27 years			Gas generation potential within 150		
	m3	ton	Average gas production in ton per year	m3	ton	Average gas production in ton per year
Carbon dioxide	31100000	1700000000000	630000000	132000000	725000000000	4800000000
Methane	31100000	46670000000	1700000000	132000000	200000000000	1300000000
NMOCs	1400	389000	14400	1000000	300000000	2000000
Total biogas	250000	200000000	7400000	265000000	220000000000	1400000000

Table4. The emitted gas from the Marvdasht landfill within the course of 27 and 150 years

The volume of the generated biogas within the course of 150 years is presented in Figure 2. As it is illustrated by this figure, the volume of the generated biogas is increased based on the increment in the amount of aggregated waste. However after one year of suspense after the operation shutdown in the landfill, the generated biogas is heavily decreased. The climax of biogas generation is observed in the year 2031 which is calculated at 4488000 m3 of annual generation. Based on the Figure 2, the biogas generation rate in the Marvdasht landfill would fall to 477800 m3 per year in 2143.

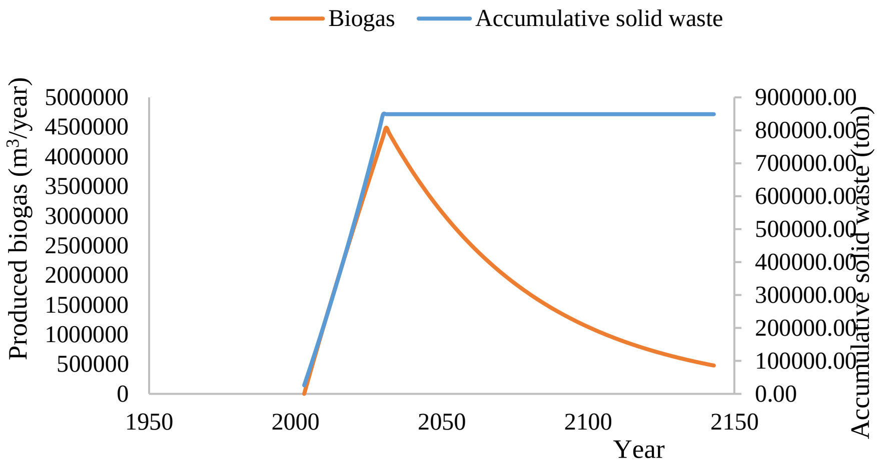

Figure 2. The aggregated gas rate and produced biogas in the Marvdasht landfill

Carbon dioxide generation rate

Carbon dioxide is the most important greenhouse gas and the main factor in global warming. Carbon dioxide in generated as the result of anaerobic decomposition of perishable portions of waste. In Figure 3, the volume of the generated carbon dioxide is presented within the years of 2003 and 2143. As it is illustrated, the volume of carbon dioxide is increased in proportion to the increased amount of waste in the landfill. This rise is continued until 2031 which is one year after the operation shutdown of Marvdasht landfill. However it would heavily fall after two year of shutdown.The climax of carbon dioxide generation is observed in 2031 which will be equal of 2244000 m3. Despite the decreasing gasgeneration after 2031, the process is continued until 1522. The annual carbon dioxide generation rate of carbon dioxide would fall to 238900 after 150 years of operation shutdown which is in the year 2143. Since carbon dioxide is heavier than air, it would move towards the bedding of the landfill.

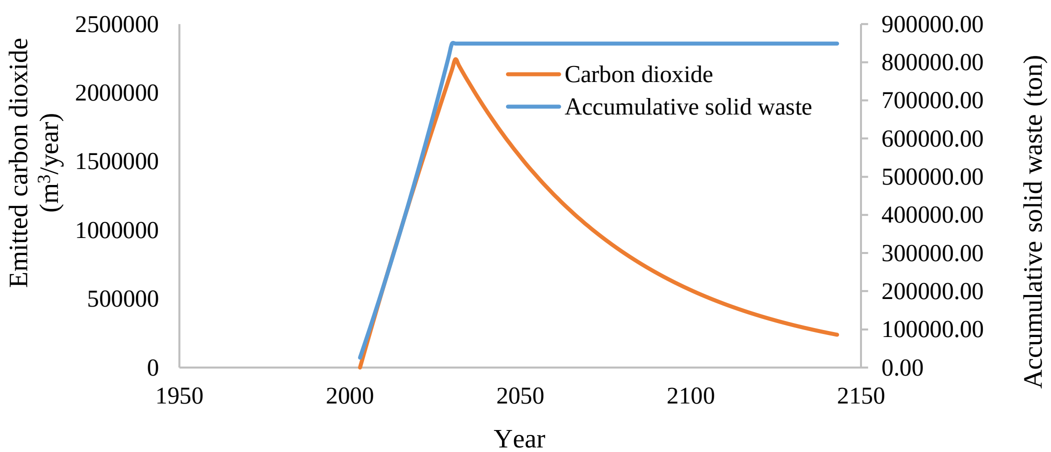

Figure 3. Carbon dioxide generation shifts in the Marvdasht landfill after 150 years

Methane production rate

Methane is one of the greenhouse gasses with ample energy. An approximate of 0.00165 MW of energy could be obtained for every cubic meter of methane. Figure 4 presents the methane production rate after 150 years of operation. The extractable amount of energy from the generated methane is also presented. The generation rate of methane would reach its climax after 1 year of operation shutdown which is equal to 3700 MW of energy. According to the statement from the Iranian Ministry of Energy in 2015, the estimated cost of electricity produced from landfills is 2900 rials per KW. The revenue obtained from the Marvdasht landfill would amount to 10 billion rials in 2031. The revenue gained from selling the electricity generated from the landfill would be 1489 billion rials after 27 years of operation. However considerable amounts of methane areextractable from the landfill of Marvdasht after closure year. By calculating the potential revenue gained from selling the generated electricity based on the current pricing, revenue of about 6346 billion rials is achievable within 150 years of operation. It is worth mentioning that the initial installation costs of required extraction equipments are not considered. Therefore it is necessary to conduct a comprehensive research on the exact cost and revenues of energy generation from the landfills. Since methane is lighter than air, it would move towards the ground surface (16). After reaching the concentration 5 to 15%, the risk of sudden explosion is increased. A sudden explosion of methane could inflict much financial and physical damage to the staff and equipments. The exposure to the high concentrations of this gas is also life threatening for the landfill staff. Therefore the extraction of this gas would be beneficial in economic, environment and health perspectives.

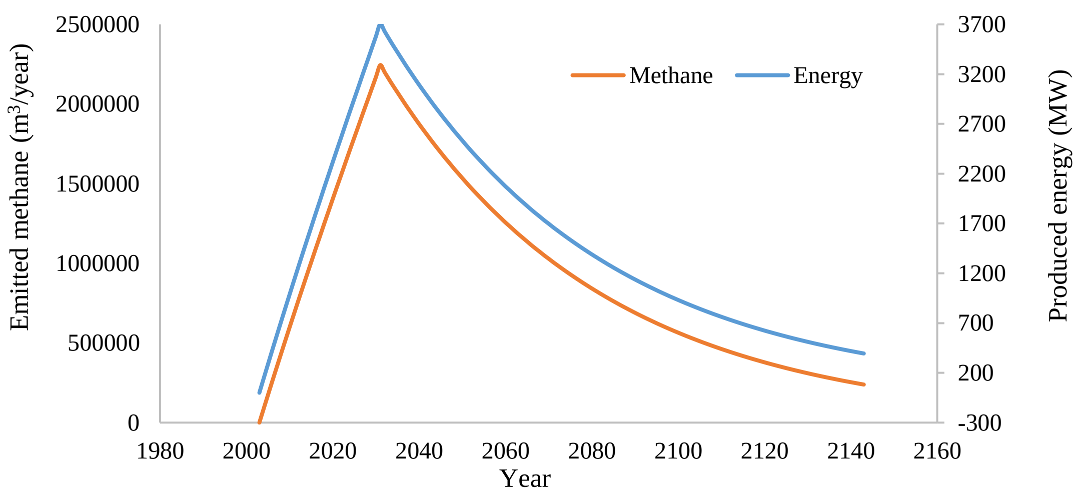

Figure 4. The volume of generated methane in Marvdasht landfill after 150 years

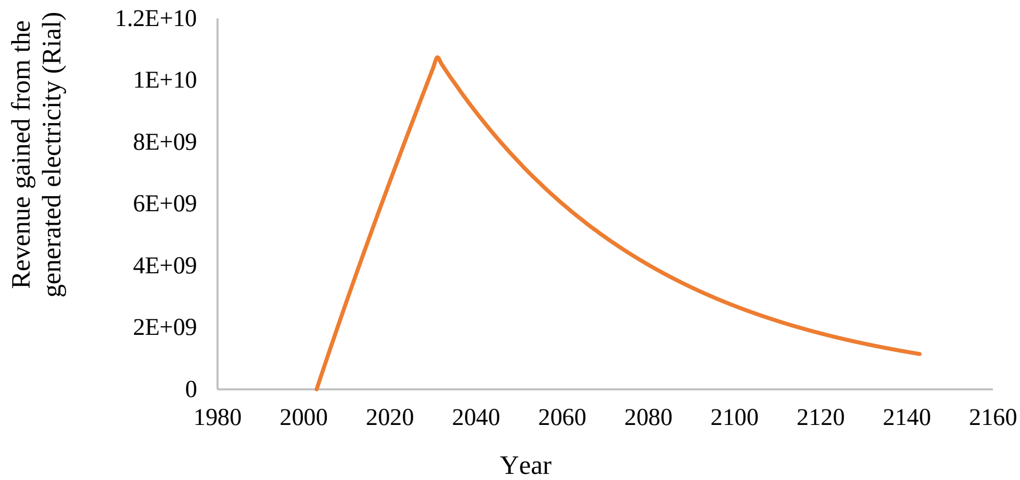

Figure 5. The obtained revenue gained from the generated electricity within 150 years

NMOCs generation rate

The NMOCs are a collection of chemical compounds with different chemical structure but similar behavior (17). NMOCs are generated and released into the atmosphere through various means including combustion, solvents, anaerobic decomposition of organic compounds and production processes (13). NMOCs could also lead to the formation of tropospheric ozone which entails much health risks for humans. Several other NMOCs including benzene or 1.3 Butadiene are also highly dangerous for humans. As it is presented in Figure 6, the emission of NMOCs is increased in proportion to the aggregated waste in the landfill which would reach a climax after a yearof operation shutdown. The volume of the released NMOCs in atmosphere would be equal to 17950 in 2031. The generated NMOCs in the landfills are relatively lower that carbon dioxide or methane, however chemical compounds such as benzene and vinyl chloride are harmful and occasionally carcinogenic. The NMOCs generation rate for 2016 was modeled using the LandGEM software. The result of this modeling is the list of 48 NMOCs that are released within the year of 2016 from the landfill. The emission rate of compounds such as vinyl chloride and benzene into the atmosphere is estimated respectively as 0.041 and 0.091 tons in 2016.

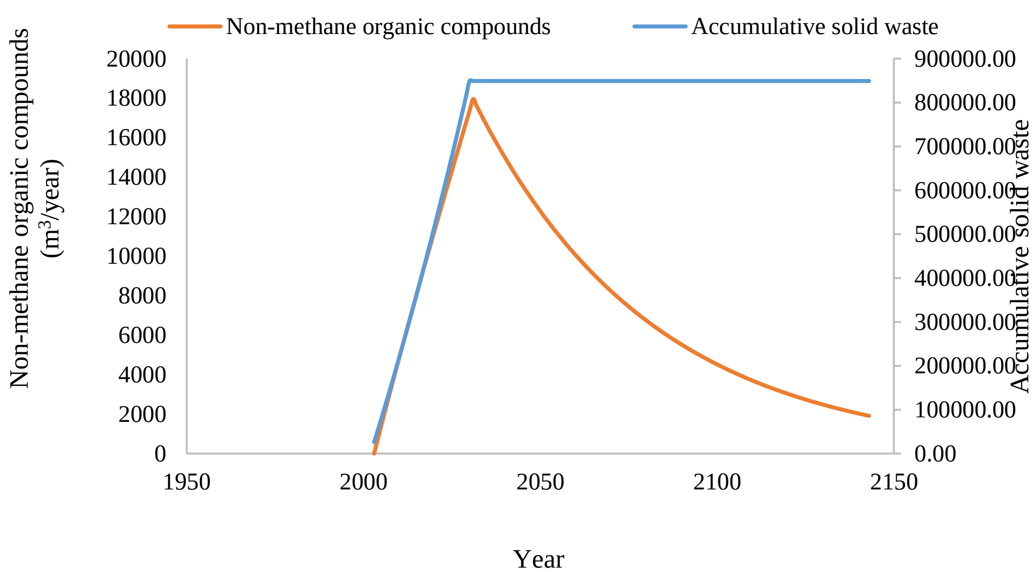

Figure 6. The total emission rate of NMOCs within 150 years

Pollutants	Emission rate	
	Ton/year	m^3/year
Total landfill gas	2717	2175000
Methane	725.6	1088000
Carbon dioxide	1991	1088000
NMOC	31.190	8701
1,1,1-Trichloroethane (methyl chloroform) - HAP	0.006	1.044
1,1,2,2-Tetrachloroethane - HAP/VOC	0.017	2.393
1,1-Dichloroethane (ethylidene dichloride) - HAP/VOC	0.021	5.221
1,1-Dichloroethene (vinylidene chloride) - HAP/VOC	0.002	0.435
1,2-Dichloroethane (ethylene dichloride) - HAP/VOC	0.004	0.892
1,2-Dichloropropane (propylene dichloride) - HAP/VOC	0.002	0.392
2-Propanol (isopropyl alcohol) - VOC	0.272	108.8
Acetone	0.037	15.23
Acrylonitrile - HAP/VOC	0.030	13.70
Benzene - No or Unknown Co-disposal - HAP/VOC	0.013	4.133
Benzene - Co-disposal - HAP/VOC	0.078	23.93
Bromodichloromethane - VOC	0.046	6.743
Butane - VOC	0.026	10.88
Carbon disulfide - HAP/VOC	0.004	1.262
Carbon monoxide	0.355	304.5
Carbon tetrachloride - HAP/VOC	0.000	0.009
Carbonyl sulfide - HAP/VOC	0.003	1.066
Chlorobenzene - HAP/VOC	0.003	0.544
Chlorodifluoromethane	0.010	2.828
Chloroethane (ethyl chloride) - HAP/VOC	0.008	2.828
Chloroform - HAP/VOC	0.000	0.065
Chloromethane - VOC	0.005	2.610
Dichlorobenzene - (HAP for para isomer/VOC)	0.003	0.457
Dichlorodifluoromethane	0.175	34.80
Dichlorofluoromethane – VOC	0.024	5.656
Dichloromethane (methylene chloride) – HAP	0.108	30.45
Dimethyl sulfide (methyl sulfide) – VOC	0.044	16.97
Ethane	2.421	1936
Ethanol - VOC	0.113	58.73
Ethyl mercaptan (ethanethiol) – VOC	0.013	5.003
Ethylbenzene - HAP/VOC	0.044	10.01
Ethylene dibromide - HAP/VOC	0.000	0.002
Fluorotrichloromethane - VOC	0.009	1.653
Hexane - HAP/VOC	0.051	14.36
Hydrogen sulfide	0.111	78.31
Mercury (total) - HAP	0.000	0.001

Methyl ethyl ketone - HAP/VOC	0.046	15.44
Methyl isobutyl ketone - HAP/VOC	0.017	4.133
Methyl mercaptan - VOC	0.011	5.438
Pentane – VOC	0.022	7.178
Perchloroethylene (tetrachloroethylene) – HAP	0.056	8.049
Propane - VOC	0.044	23.93
t-1,2-Dichloroethene - VOC	0.025	6.091
Toluene - No or Unknown Co-disposal - HAP/VOC	0.325	84.84
Toluene - Co-disposal - HAP/VOC	1.417	369.8
Trichloroethylene (trichloroethene) - HAP/VOC	0.033	6.091
Vinyl chloride - HAP/VOC	0.041	15.88
Xylenes - HAP/VOC	0.115	26.10

Table 5. The emission rate of NMOCs into the atmosphere in 1394

The evaluation of emission into the atmosphere

Calculations suggest that in 2016 the emission rate of carbon dioxide, methane and NMOCs in Marvdasht landfill in respectively equal to 0.0046, 0.0126 and 0.000197 g/s.m3. The emission of the aforementioned gasses into the atmosphere was modeled by using the Screen View software. The modeling results for carbon dioxide and methane are presented in Figure7 and for the NMOCs are presented in Figure 8. It is worth mentioning that the Figures 7 and 8 present the pollutant concentrations simply in the direction of the wind which is equal to 1 meter per hour. As it is shown, the concentration of the pollutant in a 1000 meter radius of the landfill is being decreasing with high slope. The concentration of carbon dioxide, methane and NMOCs in a 100 meter distance in respectively equal to 0.437, 0.159, 0.006 g/m3which would reach 0.0388, 0.014 and 0.0006 g/m3 in a 1000 meter distance. Since the average concentration of carbon dioxide in the atmosphere is equal to 0.00756 g/m3, the generated carbon dioxide in the landfill can be increased in concentration in a 100 and 1000 meter distance which would respectively be 0.4445 and 0.0463 g/m3.

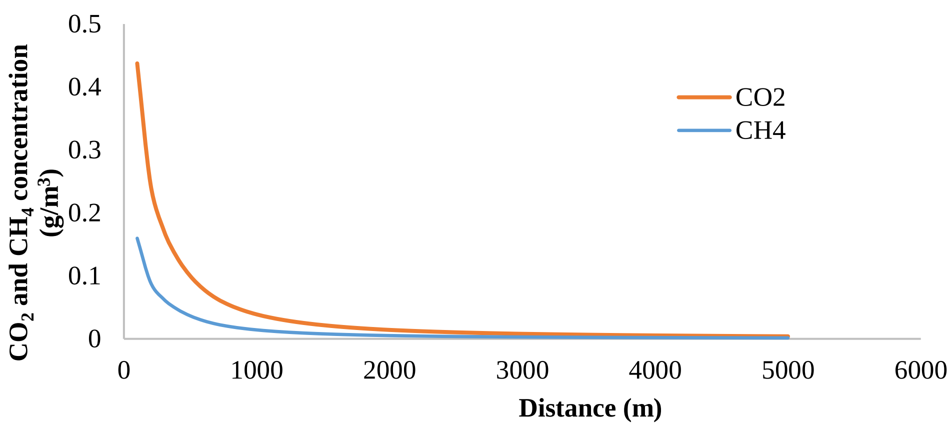

Figure 7: Concentration shifts of carbon dioxide and methane with changes in distance from the landfill

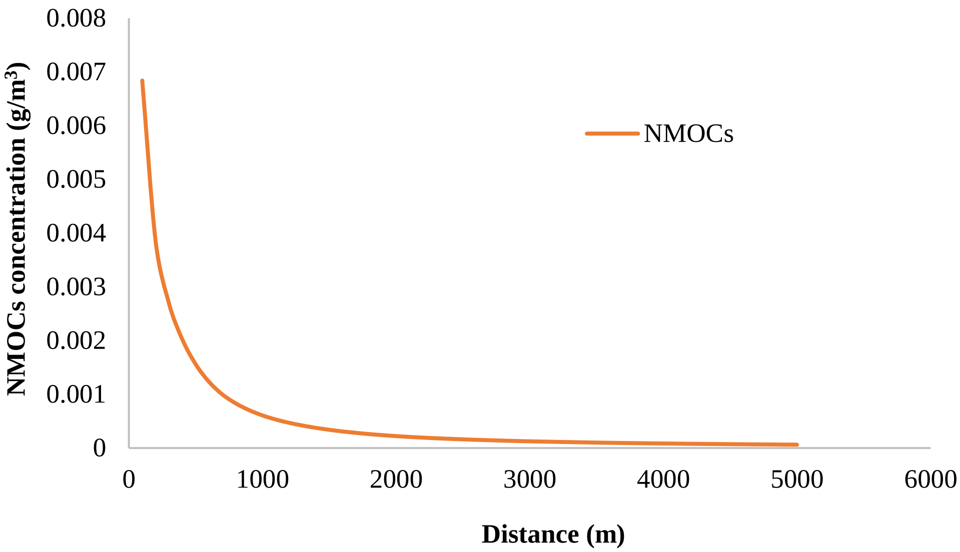

Figure 8. The concentration shifts of NMOCs with changes in distance from the landfill

Conclusions

In this study, all the required information regarding the transportation and disposal of municipal solid wastes of Marvdasht were gathered and consequently led to the modeling of the carbon dioxide, methane and NMOCs emission into the atmosphere. The results obtained from this modeling suggest that within the years of 2003 and 2031 the amount carbon dioxide, methane and NMOCs will respectively be equal to 17×1011, 4667×107 and 3.89×105 tons. The carbon dioxide and methane are among the most important greenhouse gasses which would have positive effects on global warming if prevented. Since the majority of the NMOCs are highly toxic and carcinogenic thus the decreased emission of these gasses into the atmosphere would prevent diseases such as cancer. It is suggested to extract the generated biogas on site in order to prevent their emission. In this study the revenue gained by utilizing the extracted methane to produce energy was estimated within the course of 27 operational years of the landfill which is calculated at 1489 billion rials. It is worth mentioning that the above estimation did not take into the account the initial establishment costs for the required equipment for the extraction and treatment of the landfill biogas. Therefore comprehensive research is required in order to estimate the exact cost and revenue of energy generation in the landfills.

The results obtained in this study can be used for the purpose of design and establishment of extraction and treatment systems of the produced gasses in the landfill of Marvdasht.

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